RESEARCH OF NATIONAL GEODETIC NETWORK ELEVATIONS AT EASTERN PART OF LATVIA

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Abstract
Along with the development of the technological possibilities, the Global Positioning Satellite System (GNSS) is increasingly used in geodetic measurements. Using GNSS, measurements are performed in horizontal plane as well as for point elevation determination. The aim of the article is to demonstrate that the GNSS measurements' static mode has a high accuracy. To achieve the aim the following objectives were set: 1) to perform global positioning measurements in Class I national leveling network, 2) to calculate the elevation above the sea level, 3) to evaluate the accuracy of performed GNSS measurements. The following research methods were used: static measurement method and analytical method for comparison of the obtained data.

Key words: GNSS, point heights, elevations, class I leveling, measurement accuracy.

Introduction

More and more the advantages of the Global Navigation Satellite System (GNSS) are used across the world and in Latvia. With help of GNSS, plane coordinates and heights could be obtained anywhere on the Earth. Determination of heights between points with levelling method can take up for several days, but using the benefits of GNSS, measuring points with static method takes at least 4 hours obtaining almost similar data in comparison with performing leveling. This study is an attempt to find out whether sufficiently accurate data can be obtained with GNSS measurement techniques.

The aim of the article is to demonstrate that the GNSS measurements static mode has high vertical measurement accuracy. To achieve the aim the following objectives were set: 1) to perform global positioning measurements in national Class I leveling network, 2) to calculate the elevation above sea level, 3) to evaluate the accuracy of performed GNSS measurements. Within the study measurements of Class I leveling network geodetic signs were performed, measured by GNSS method in two different time periods – on 14th December, 2012 and 22th November, 2013. These measurements were performed in the static mode for 4 hours throughout the territory of Latvia at the same time. Why the GNSS method was used? At first, it allows to significantly reduce the measurement time and the number of staff compared to the classic levelling. In this method it is necessary only to center on the geodetic point and take measurements in the static mode. Developing selected GNSS method, surveying and calculating ellipsoidal coordinates for several times, it is possible to organize the systematic control of height changes at the height system's output zero point and at the selected regional reference points. For the points where it is not possible to make direct measurements with GNSS, there would still remain the need for precise geometric levelling. The second direction of GNSS application is to use it for new height point determination in the national normal height system. (Lazdāns u.c., 2009) For such point determination an accurate geoid model throughout the country is required. At this moment in Latvia national geoid model LV'98 is used providing 8-10 cm accuracy. In the future, the geoid model with 2 cm accuracy is planned to develop for the entire territory of Latvia (Reiniks, 2010). New satellites are launched into the Earth orbits which can provide more accurate measurement results. The latest GPS III satellites are planned for 25% longer service life; they would prove three times better accuracy and eight times better protection against signal interference. These satellites were started to launch into space from the end of 2013. On the basis on the results of this study, it is possible to determine the Earth's crust vertical movements, register their parameters and create modules. This type of the study has not been carried out previously in Latvia, so there is no methodology for this type of the research.

Methodology of research and materials

GNSS measurements were performed in Class I levelling network. As the basis for the comparison of measurement results 2000 – 2010 reconstructed class I leveling network was used resulting in the currently topical GNSS elevation measurement accuracy comparison in relation to geometric levelling results. For the measurements in class I leveling network with GNSS receivers, the existing Class I leveling network nodal points were surveyed to ascertain the point position and an open horizon around the point to be sure that there would not be interference with satellite signals reception. During the follow-up it was identified weather the point is precisely located at the site, as well as it was shortly measured with GNSS receiver in real time to verify the sufficient satellite location over a point. If it was found out that the site of the geodetic sign is not suitable for application of GNSS method, the search and survey for next point of levelling line was carried out until the suitable point was found and then surveying was performed from that point. During the measurements the suitable settings for GNSS receivers were installed to get the correct results.

Measurements were performed with GNSS receivers in static mode for at least 4 hours. At first this kind of campaign took place on 14th December, 2012, the second campaign was on the 22th November, 2013. Measurements were carried out for 4 hours – from 10am to 2pm. For this study 3 class I leveling points were selected which were measured in both campaigns – ground benchmark 1415 located between Jēkabpils and Pļaviņas; fundamental benchmark 1484 which also is the nodal point and is located near Pededze; ground benchmark 1001 near Zilupe (see Figure 1). For the processing of measurements the LatPOS network data were used. On each of these points the company Leica GNSS instrument was installed.

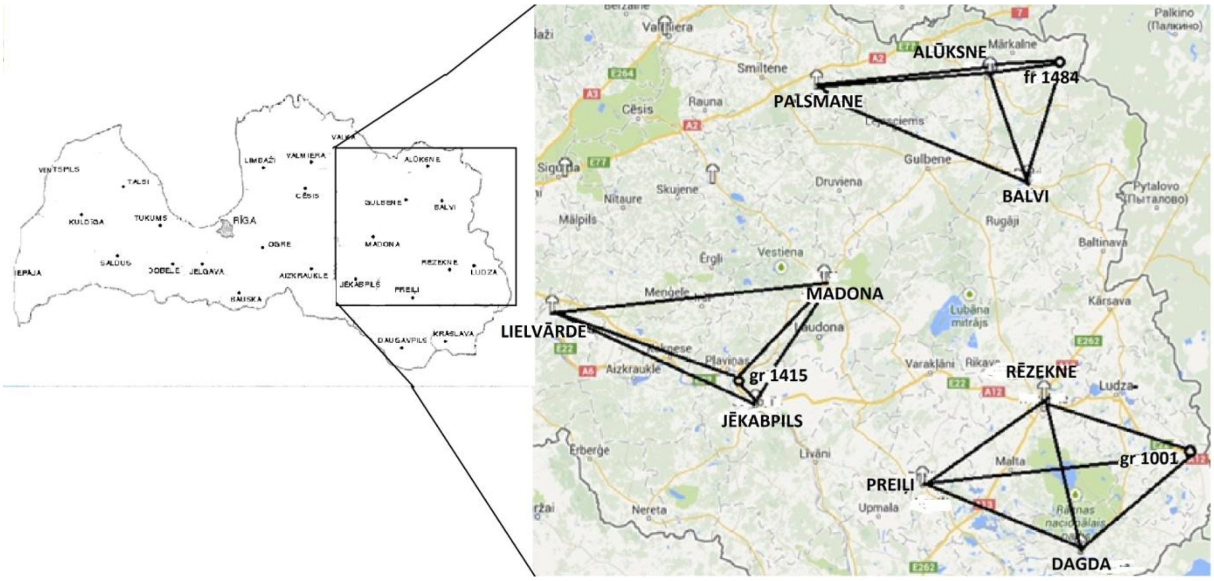

Fig. 1. Class I levelling network points locations and GNSS vectors to the nearest LatPOS base stations.

For data processing the data from 3 nearest LatPOS base stations for each class I levelling network points, used in this study, were obtained. These data were obtained from the LatPOS website, accordingly selecting these base stations. Three nearest LatPOS network base stations for geodetic point No. 1415 is Jēkabpils, Madona and Lielvārde; for point No. 1484 – Alūksne, Balvi and Palsmane, but for point No. 1001 – Rēzekne, Dagda and Preiļi (see Figure 1).

After obtaining the data from GNSS receivers and LatPOS website, for measurements equalizations Trimble Business Center measurement adjustment program were used. This program allows to see accuracy of the measurements over the measurement time. When adjustments are made to obtain accurate data, LatPOS validated base station coordinates were also taken into account. After the data adjustment, the vectors accuracy from the base station to point as well as precise point coordinates and heights were obtained. According to the adjusted data, elevations between the class I points used in this study were calculated which then were compared with the data received from Latvian Geospatial Information Agency (LGIA) obtained with class I geometric levelling method.

Discussions and results

GNSS vector accuracy was obtained from the Trimble Business Center program adjusted data allowing to pinpoint the coordinates of point and height. Table 1 shows the calculated GNSS vector accuracy from measurements performed on14th December, 2012. Obtained vector accuracy allows to determine the height precision, which allows to determine elevation between points.

Table 1

GNSS vector accuracy

From the point	To the point	Horizontal accuracy (m)	Vertical accuracy(m)	V^^{2} (vector)	V^^{2} (to the point)
Madona	Jēkabpils	0.003	0.010	0.000100	X
Madona	1415	0.004	0.013	0.000169	0.000169
Madona	Lielvārde	0.006	0.017	0.000289	X
Jēkabpils	1415	0.004	0.014	0.000196	0.000196
Lielvārde	Jēkabpils	0.005	0.014	0.000196	X
Lielvārde	1415	0.006	0.017	0.000289	0.000289
Rēzekne	Preiļi	0.003	0.011	0.000121	X
Rēzekne	Dagda	0.003	0.011	0.000121	X
Preiļi	Dagda	0.004	0.012	0.000144	X
Preiļi	1001	0.007	0.020	0.000400	0.000400
Dagda	1001	0.004	0.013	0.000169	0.000169
Rēzekne	1001	0.007	0.020	0.000400	0.000400
Palsmane	1484	0.008	0.025	0.000625	0.000625
Palsmane	Balvi	0.006	0.016	0.000256	X
Balvi	1484	0.004	0.016	0.000256	0.000256
Balvi	Alūksne	0.003	0.009	0.000081	X
Palsmane	Alūksne	0.005	0.013	0.000169	X
Alūksne	1484	0.004	0.014	0.000196	0.000196
			SV=summ	0.004177	0.002700
			d=SV/n	0.000232	0.0003
			s=SQRT(d)	0.015233	0.017321

Table 1 shows that the mean square vector accuracy is 0.015 m, but accuracy of the vectors is 0.017 m, which is a very good indicator. GNSS vector precision, acquired by 22th November, 2013 data adjustment, is depicted in Table 2.

Table 2

GNSS vector accuracy

From the point	To the point	Horizontal accuracy (m)	Vertical accuracy(m)	V^^{2} (vector)	V^^{2} (to the point)
Madona	Jēkabpils	0.002	0.009	0.000081	
Madona	1415	0.003	0.011	0.000121	0.000121
Madona	Lielvārde	0.003	0.009	0.000081	X
Jēkabpils	1415	0.003	0.013	0.000169	0.000169
Lielvārde	Jēkabpils	0.003	0.009	0.000081	X
Lielvārde	1415	0.003	0.010	0.000100	0.000100
Rēzekne	Preiļi	0.002	0.009	0.000081	X
Rēzekne	Dagda	0.002	0.009	0.000081	X
Preiļi	Dagda	0.003	0.009	0.000081	X
Preiļi	1001	0.003	0.011	0.000121	0.000121
Dagda	1001	0.003	0.012	0.000144	0.000144
Rēzekne	1001	0.003	0.012	0.000144	0.000144
Palsmane	1484	0.018	0.018	0.000324	0.000324
Palsmane	Balvi	0.003	0.009	0.000081	X

Table 2 continuation

From the point	To the point	Horizontal accuracy (m)	Vertical accuracy(m)	V^^{2} (vector)	V^^{2} to the point)
Balvi	1484	0.003	0.016	0.000256	0.000256
Balvi	Alūksne	0.003	0.010	0.000100	X
Palsmane	Alūksne	0.003	0.009	0.000081	X
Alūksne	1484	0.004	0.019	0.000361	0.000361
			SV=sum	0.002488	0.001740
			d=SV/n	0.000138	0.000193
			s=SQRT(d)	0.011757	0.013904

Table 2 shows that the mean square vector accuracy is 0.012 m, the geodetic vector accuracy is 0.014 m. The comparison of the measurements taken in 2013 with measurements taken in 2012 shows that more accurate measurements were made in 2013. Perhaps this can be explained by better placement of satellites during the measurements made in 2013.

Table 3, Table 4 and Table 5 shows the height differences of class I levelling network points measured in 2012 and 2013; the pictures shows the measured point and its neighborhood.

Table 3

The point heights by GNSS measurements

Year	Point No.	Height, m	Calculated height error, m
2013	1484	156.784	0.023
2012	1484	156.766	0.035

Fig. 2. Class I leveling network point No. 1484 in 2012 (left) and in 2013 (right).

As shown in Table 3, class I levelling network point 1484 has height difference between the measurements made in 2012 and 2013 is 0.018 m. Height difference could be explained by the openness of the horizon, and the possibility of reception. As shown in Figure 2, the geodetic point is near the ruins and the surroundings are little overgrown with trees affecting the GNSS signal to reach the receiver and thus reducing accuracy. Estimated height errors also affect the resulting accuracy of the heights. Height error obtained form 2013 measurements has decreased by 0.012 m. Perhaps the 2012 measurement error was also affected by weather conditions, as shown in Figure 2, at the time of measurements the land was covered with snow.

Table 4

The point heights by GNSS measurements

Year	Point No.	Height, m	Calculated height error, m
2013	1001	138.613	0.018
2012	1001	138.552	0.017

Fig. 3. Class I leveling point No. 1001 in 2012 (left) and in 2013 (right).

Class I leveling network point 1001 height measurements are reflected in Table 4. Between GNSS measurements height difference is relatively large - 0.061m. The height gap could be affected by geoid model whose accuracy is up to 10 centimeters. The comparison of the calculated height errors, which practically are the same, implies that there is a good condition for measurements. Figure 3 shows that the point location is good, the horizon is open, only a small-signal obstacle is power line pole which is near by the point.

Table 5

The point heights by GNSS measurements

Year	Point No.	Height, m	Calculated height error, m
2013	1415	76.856	0.012
2012	1415	76.845	0.025

Fig. 4. Class I leveling point No. 1415 in 2012 (left) and 2013 (right).

As shown in Table 5, measurement data of point 1415 for both years are very similar; the height difference is only 1 centimeter. This could be explained by the fact that visible and opened horizon is around this point. On the other hand, comparing the calculated height error, the difference is larger - 0.013 m.

For further calculations the height values were analyzed. Table 6 shows all 3 points' heights measured with GNSS, from which the elevations between the points and their differences were calculated.

Table 6

The point heights by GNSS measurements

Point No.	Height 2012, m	Height 2013, m	Difference, m
1484	156.766	156.784	0.018
1001	138.552	138.613	0.061
1415	76.845	76.856	0.011

As it can be seen, the difference between the 2012 and 2013 measurements is up to 6.1 cm. In this case, the large effect is constellation above the horizon. The number of satellites at the time of measurements for each point was more than 10, which allows to accurately determine the location of the measuring point, but the difference is affected by the signal reception, which is essential to obtain high-precision data. Accuracy is also affected by solar activities that require additional research.

For further research interconnected class I levelling point elevations were examined acquired with geometric levelling method and measured with GNSS method. The obtained results are summarized in Table 7.

Table 7

Class I leveling network interconnected point elevations

Point Nr. to	Point Nr. from	Class I geometric leveling, m	GNSS measurement 2012, m	GNSS measurement 2013, m
1484	1001	-18.083	-18,171	-18,153
1001	1415	-61.839	-61,707	-61,757
1415	1484	79.936	79,921	79,928

Elevations between the GNSS measurements are similar, but compared to the geometric levelling they are different. Figure 5 graphically displays the elevation difference of class I levelling network points determined by geometric levelling methods and GNSS methods in both measurement campaigns. As the zero-reference line geometric levelling results were taken.

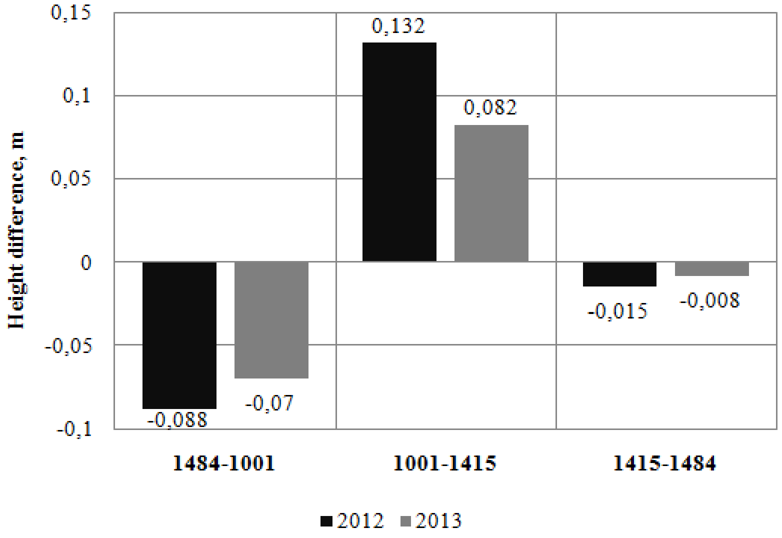

Fig. 5. Elevation difference between the geometric leveling method and GNSS measurement method, for both campaigns.

As shown in Table 5, the elevation difference between the geometric leveling and GNSS measurements for campaign of 2013 is smaller than for campaign of 2012. The biggest difference between the elevations of geometric leveling and GNSS method is 13.2 cm, but the smallest difference is 0.8 cm. The resulting reciprocal comparison shows that the best matching between elevations is for signs 1415 and 1484. Elevation differences obtained at 2013 GNSS measurements is only 8 mm, which is a good indicator. However, the relatively poor results were obtained between points in 1484 - 1001 and 1001-1414. Obtained elevations fit within the accuracy of the geoid model; however, as shown in Figure 5 the difference with geometric leveling is with opposite signs. Total difference by the 2013 GNSS measurement is 15.2 cm which could be designated as high.

Evaluating the results, one should understand that elevations obtained with GNSS quality determine the accuracy of measurements in the vertical plane which is affected by the horizon condition, solar activity, ionosphere effects, etc. The authors came to the conclusion that the geoid model accuracy increase up to 2 cm in the nearest future could be relatively difficult. Besides, it should be taken into account that class I levelling network accuracy is up to 17 mm, in the direction from west point Jūrkalne to east point Zilupe (Celms et.al, 2013). The accuracy gets worse every year, taking into account the Earth's crust vertical movements in Latvia (Celms et.al, 2007). In further occasions if the aim is actually raise and stabilize the vertical measurement accuracy using GNSS technology in the territory of Latvia, it is advisable to associate all LatPos base station antennas to class I levelling network, thereby providing an opportunity to get regular changes of height adjustments for the entire height grid. Besides, it is necessary to take yearly class I control levelling between LatPos base stations, thereby providing operative and full GNSS and geometric levelling data combining and application for state height systems maintaining. More scientific research is required for the above mentioned impact deployment on practical geoid model with possibility to increase the accuracy up to 2 cm.

In all cases within this study the results obtained with GNSS method measurement show good internal measurement results accuracy (mean vector accuracy is up to 0.02 m.) which relies on the system’s possibility to achieve the technically high precision final results, if the exclusion of other factors or compensation issues are resolved.

It should be noted that, although the levelling method is currently showing higher measurement accuracy, however, given the long levelling work performance period during which the Earth's crust movement is continuing, the obtained results in 2010 (when measurements were completed) already had been subjected to deformations, and real GNSS measurement performance time that has passed after the levelling works points to the additional differences in results that might have emerged in this study, but has not yet been identified within a small number of measurements (only two campaigns in order to compare the results of leveling) (Celms et.al, 2012).

If further research results of GNSS technology vertical measurements will be closer to stable 0.02 m maximum deviation values, this method should be recognized as equivalent to levelling work results for elevation data acquiring between points in cases of long-distances (distances greater than 300 km), which will provide the basis for organization of annual national height system precision monitoring.

In the comparison process, levelling elevations accepted as a stencil also should be seen as relative, therefore it is necessary both new levelling work cycle run and repeated GNSS campaigns to continue to obtain the profound basis for comparing and evaluating; their results would show real elevations and their changes of dynamic state, as well as criteria of achieved accuracy.

Conclusions and proposals

1. Performing the measurements with GNSS method in static mode for 4 hours, the obtained average vector accuracy is up to 0.02 m.
2. Performing measurements with GNSS receiver it is important to note that the horizon is open around the measurement point.
3. Using GNSS for determination of elevation between measurement points, measurements should be performed at the same time. Elevation estimates between GNSS measurements obtained in different time periods may show false positives.
4. The difference between GNSS method obtained elevations and class I geometrical levelling elevations was in the range from -0.070 to + 0.082 m during 2013 campaign, but the difference between GNSS method obtained elevations and class I geometrical levelling elevations was in the range from + 0.132 to -0.088m during the 2012 campaign.
5. In order to determine the GNSS methods application possibilities for height determination, it is important to compare GNSS method obtained data with class I geometric levelling elevations.
6. It is advisable to continue such measurements every year in order to better assess the factors of elevation changes. On December 2013 the GPS III generation satellite was launched, which is

more powerful and accurate and which could show the difference with previously obtained data.

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